



# Impact of landscape patterns on herb-layer diversity and seed size of *Schima superba* in urban remnant vegetation: A case study in Guangzhou, Southern China

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Received: 10 January 2022 / Revised: 20 April 2022 / Accepted: 14 June 2022 / Published online: 10 January 2023  
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## Abstract

In order to explore which ecological strategies the remnant vegetation is taken to adapt to urbanization, we investigated three kinds of typical remnant vegetation (grassland, plantation, and secondary forest) in 16 sample sites along the urban–rural gradient in the city of Guangzhou. In this study, we examined plant species composition, and plant diversity, and analyzed the seed of the dominant tree species *Schima superba* (*S. superba*) in the secondary forest sites. Those indicators are strongly related with ecological strategies. Eighteen landscape pattern characteristics were determined to reveal the extent of landscape fragmentation. Geographic Information System (GIS), linear regression, and Canonical Correspondence Analysis (CCA) were conducted to analyze the influence of landscape pattern characteristics on plant communities. Results showed that (1) Fragmentation of landscape patterns caused by urbanization has a negative impact on the diversity of herb-layer plants, the dominant species of grassland in the city center are mainly weeds, such as *Bidens pilosa* and *Neyraudia reynaudiana*. (2) In order to adapt to the pressure of landscape fragmentation, seeds of *S. superba* have developed into a larger size, with a competitive advantage over smaller ones. (3) Two different ecological strategies of plant communities adapting to urbanization: The pioneer weeds in grasslands, with high reproductive and dispersal ability, have adopted a r-selection strategy and the dominant tree species with higher survival rates, larger individuals, and longer life spans, have adopted a K-selection strategy to resist disturbance, as well as with a larger seed size to increase viability and settlement ability.

**Keywords** Ecological strategies · Herb-layer plant diversity · Landscape fragmentation · *Schima superba* · Seed size · Urbanization · Weeds

## Introduction

Today, the ever-increasing people and urbanization in cities pose a huge challenge to the urban ecosystem environment (Yang et al. 2021). These changes in landscape structure result in habitat loss and fragmentation which in turn affect biodiversity and ecosystem processes in urban areas (Jennifer and Wu 2012). Urban vegetation, a key component of urban ecosystem, has been eroded by construction and separated from farmlands, roads and buildings which limited species seed dispersion capacity, biodiversity, and structures (Li et al. 2020). Making it essential to explore the interactions among landscape pattern characteristics, and vegetation during the urbanization process.

Previous studies suggest that problems such as habitat fragmentation, low biodiversity, lack of native species resources, and limited seed dispersion capacity were caused by the deficiency in similar adjacent forest connections when

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the fragmented patches have been gradually converted into quasi-island ecosystems (Mei et al. 2012; Delong et al. 2020). Some scholars found that the factors of adjoining land-use patterns, distance from forest edge, forest patch size, and the resulting interactions had a profound impact on plant species richness in urban forests (Guirado et al. 2007; McDonnell and Hahs 2013). But most studies have focused on how patch size and isolation affect the distribution of plants in fragmented landscapes (Williams et al. 2006; Godefroid et al. 2007). Recently, Yang et al. (2021) analyzed the relationship between woody plant diversity and urban forest landscape metrics according to a distance gradient using field measurements of diversity and imagery delineated urban forest patches, reported that the woody plant species richness, Shannon–Wiener diversity, and evenness gradually increased, and Lv et al. (2019) further reported that Patch density (PD), landscape shape index (LSI), and Shannon's diversity index (SHD) are increased linearly to woody plants species richness in the urban forest. But for the urban remnant vegetation, especially the herb-layer plant with high urban disturbance, are more necessary to study how they can survive. Pioneer plants, for example, are hardy species that are the first to colonize previously disrupted or damaged ecosystems (Lee et al. 2020). In urban, Pioneer plants, mainly weeds and annual herbaceous plants, are often able to withstand high air pollution, trampling, alkaline, compacted, and nitrogen-rich soils those are generated by the high degree of urbanization (McKinney 2006), so they are easily replaced by late-successional species in the later period. Wang et al. (2005) summarized three kinds of plant species frequently found in the remnant stands in urban areas in Southern China: (1) edge species, such as *Rhus chinensis* and *Lindera benzoin*; (2) species commonly found in human settlements, such as *Broussonetia papyrifera* and *Erigeron annuus*; (3) species resistant to iterative deforestation, such as *Loropetalum chinensis*, reported that plants with a fast growth rate and a short lifespan often appear in habitat under a high degree of human disturbance. Although urbanization has a negative impact on these species, there are still well adapted to urban habitats (McKinney 2002; Kowarik 2008; Williams et al. 2009). Therefore, protecting and restoring the high quality of vegetation in a city environment is one of the most pressing issues confronting city planners. But for now, there still remains unsolved about how remnant vegetation responds to landscape fragmentation, we need to figure out which reproduction strategies are adopted by those species in order to adapt to the urbanized disturbance for the protection and management of urban vegetation in the future.

Recently, trait-based approaches have been applied to predict the effects of plant compositions on various environmental factors (Wang et al. 2021). Functional traits (PFTs), may be used to inform restoration strategies by indicating whether native and exotic species are likely

to occupy different niches (i.e., dissimilar traits indicate different resource strategies) (Hallett et al. 2017). Over the past decade, there have been many studies carried out on PFTs classifications, and their relationship with climate change and environmental factors (Hillerislambers et al. 2012). Many studies used soft traits (characteristics which are relatively easy to obtain and quantify, such as growth type and life type) to evaluate plant adaptation. The combination of seed mass and seed shape (both soft traits) was found to be a good predictor of seed persistence (hard trait) in temperate-zone seed banks, with small and relatively round seeds surviving the longest periods of burial in the soil (Thompson et al. 1993; Zhang and Sta 1999). It's been encouraged to combine soft-trait measurements according to the measurement of further (often harder) traits with proven large-scale ecological significance. Therefore, it might be a better way to evaluate the adaptation of plant communities to urbanization pressure under various urbanization levels by combining soft traits such as seed quality and size, relative growth rate, photosynthetic capacity, etc. (Cornelissen et al. 2003). In addition, the change of landscape pattern is often associated with plant reproductive traits. A comprehensive analysis of data from Europe and the United States showed that traits can reduce plant dispersal (such as large seed, low seed strength), and slow down the cloning speed of plants (Verheyen et al. 2003). Hence, seed size may serve as an indicator of plant reproduction strategies. Most studies found that seed quality is mainly related to the environmental (temperature, precipitation) (Murray et al. 2004) and geographical factors (Miyazawa and Lechowicz 2004; Yamada and Miyaura 2005), Auckland, Chicago, Melbourne, New York, Singapore, and Worcester, MA had higher rates of extinction (> 0.08% species per year), where short-statured, small-seeded plants were more likely to go extinct (Duncan et al. 2011). But those studies are less on landscape factors.

Guangzhou has experienced rapid urbanization, and its development in land use along the city center outwards has expanded disorderly. The successional sequence of climax vegetation is grasslands, coniferous forests, mixed coniferous and broad-leaved forests, and evergreen broad-leaved forests. *Schima superba* (*S. superba*) is the dominant species and common species for this vegetation, with representative and typicality, which are scattered in different urban landscape patterns in this city. It is advisable to consider these typical plants with less human disturbance in urban areas as research objectives and to explore how landscape pattern characteristics affect the remnant vegetation in the area. Therefore, we can investigate them as the natural experimental sites, and explore the following questions: (1) How did the landscape pattern characteristics impact the species composition and diversity in remnant vegetation? (2) Which strategies did the plant community adopt to respond

to the landscape fragmentation? (3) How did the seed size of *S. superba* respond to landscape fragmentation?

## Materials and methods

### Study area

Since the 1970s, Guangzhou has experienced a rapid transition from an agricultural site to an industrial and technological economy. The construction area increased from 1558.4 km<sup>2</sup> in 1992 to 1898.4 km<sup>2</sup> in 2015 (Statistics Bureau of Guangzhou Municipality 2016). Since 1990s, along with the rapid urbanization evolution, the vegetation coverage in urban areas has decreased (Xia and Gong 2006). As one of the most densely populated cities, there are only 290 km<sup>2</sup> of natural secondary forest in Guangzhou, which appear in reserve, *fengshui* forests, and scenic forests, accounting for 9.4% of total forest area (mainly plantation area) and 3.9% of Guangzhou (Zhang 2004), while grassland and artificial forests occupy most of the urban vegetation.

### Sampling

In our study, we selected three typical types of remnant vegetation, including 4 grassland, 3 plantation, and 9 secondary forests as subjects in 16 sample sites under different landscape patterns in Guangzhou (Fig. 1 and Appendix 1). According to the technical guidelines for biodiversity monitoring (2014), the large forest observation plots shall be  $\geq 1$  ha, so we set three plots (each 20  $\times$  20 m<sup>2</sup>) in the sample sites for a total of 48 sample plots. A total of 1.92 ha. In order

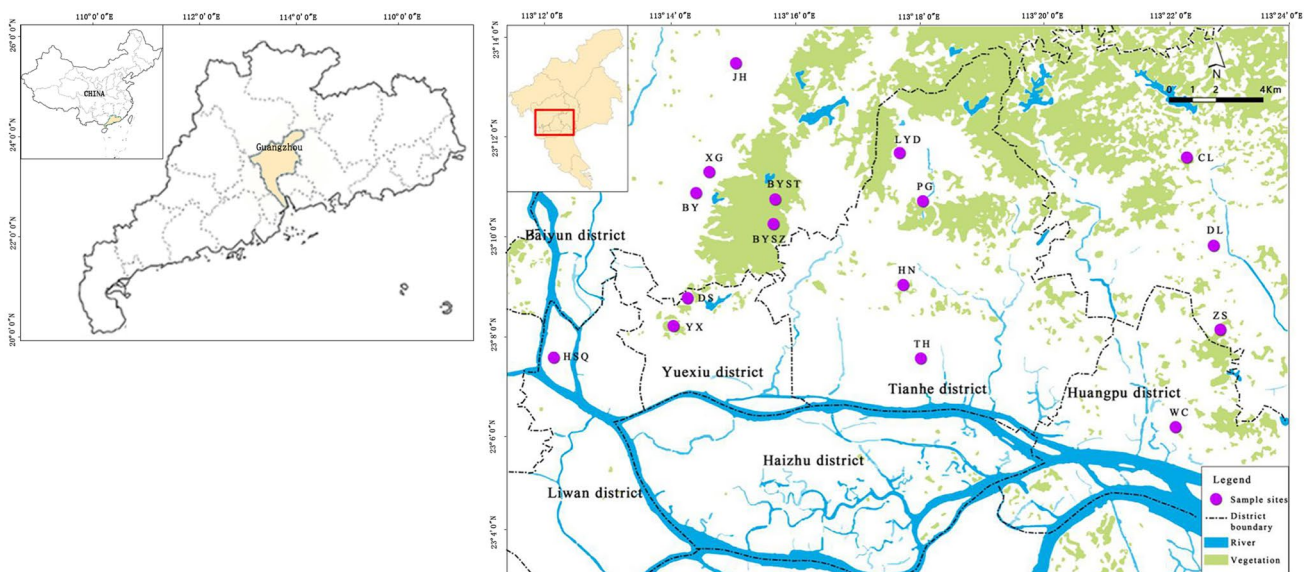
to reduce the influence of soil types, climate, and severe anthropogenic interference, these sample sites were selected through the survey based on the following criteria: (1) similar soil types, latosolic red soil; (2) similar orientation; (3) haven't experienced obvious natural or extensive anthropogenic disturbances, such as gaps, fires, pests, mowing, and selective cutting; (4) lacking natural regeneration; (5) patch area  $> 5$  km<sup>2</sup>; (6) at least 30 m distance from the main road.

### Vegetation survey

Plant species in three sample plots (each 20  $\times$  20 m<sup>2</sup>) in each study site were surveyed from March 2014 to March 2015. Woody species, trees with Diameter Breast Height (DBH) at 1.3 m  $> 2$  cm, were counted and identified in each plot. Shrubs and herbs in the same plot were counted and identified in four randomly distributed 5  $\times$  5 m<sup>2</sup> subplots and four 1  $\times$  1 m<sup>2</sup> subplots, respectively. The species, numbers, height, density, canopy, and coverage of tree, shrub, and herb layers were counted and recorded. A total of 201 species (belonging to 158 genera and 73 families) were recorded. Including 1277 trees (DBH  $\geq 2$  cm) representing 53 species (40 genera and 24 families), 136 shrub-layer species (102 genera and 51 families), and 121 herb-layer species (106 genera and 54 families) were also recorded.

### Seed size

From June to October 2014, *S. superba* in secondary forests of 27 sample points are contained by nine sample sites (BYST, BYSZ, LYD, PG, HN, CL, DL, ZS, WC), *S. superba* is a common and dominant type of species in the secondary



**Fig. 1** The map of 16 sample sites in different landscape pattern in Guangzhou, Southern China

forests of nine sample sites. The other seven sample sites were grassland and plantation, the dominant species are *Neyraudia reynaudiana* (in 12 sample points) and *Pinus massoniana* (in 9 sample points) respectively. Since these two species did not produce fruits during the survey period, they were not analyzed. So the seed sizes of the *S. superba* were selected as the indicators to reflect the relationship between PFTs of trees and landscape fragmentation. Five adult trees of *S. superba* were randomly selected as sample trees in each sample plot. In total, 135 adult trees of *S. superba* were investigated. We collected the capsules of *S. superba* from the end of September to early October when capsules were mature with micro-cracks. Capsules were oven-dried for 1–2 days, then sun-dried for 3–4 days. We screened the seeds after peel cracking. Thirty seeds were collected from each tree to measure the seed size (mm) (length, width, and thickness).

### Characteristics of the landscape patterns around urban forests

Based on the land use types data obtained from the land-use status map of Guangdong province that was extracted from the Remote Sensing Image. The optimal radius of 400–600 m was used to analyze the gradient of the landscape pattern in Guangzhou city (Zhu et al. 2011), which presents a continuous surface and is recorded in raster format, and it is conducive to directly reveal driving forces at local level, and it can be used to compare the landscape pattern visually. Therefore, we calculated the land-use types (roads, impervious surface, stands) and the landscape pattern indices of each sample plot and in circular buffers with a radius of 500 m from the center of each plot. The landscape pattern indices included the following indicators (Appendix 2).

### Data analysis

The biodiversity indices were analyzed using with R Language 2.11.0 (Magurran 1988).

#### (1) Shannon–Wiener index (H)

$$H = - \sum P_i \ln P_i$$

where  $P_i$  is the relative abundance of the  $i$  species at each plot,  $\ln$  is the natural log, and  $H$  describes the species richness and the equitability of individual distribution within species.

#### (2) Simpson index (D)

$$D = 1 - \sum P_i^2,$$

where  $P_i$  is the proportion of the individuals in species  $i$ , and  $D$  reflects the dominance in the community;

#### (3) Margalef index = $(S - 1) / \ln N$ ;

where  $S$  is the total number of species in the community, and  $N$  is the total number of individuals observed;

#### (4) Gleason index = $S / \ln A$ .

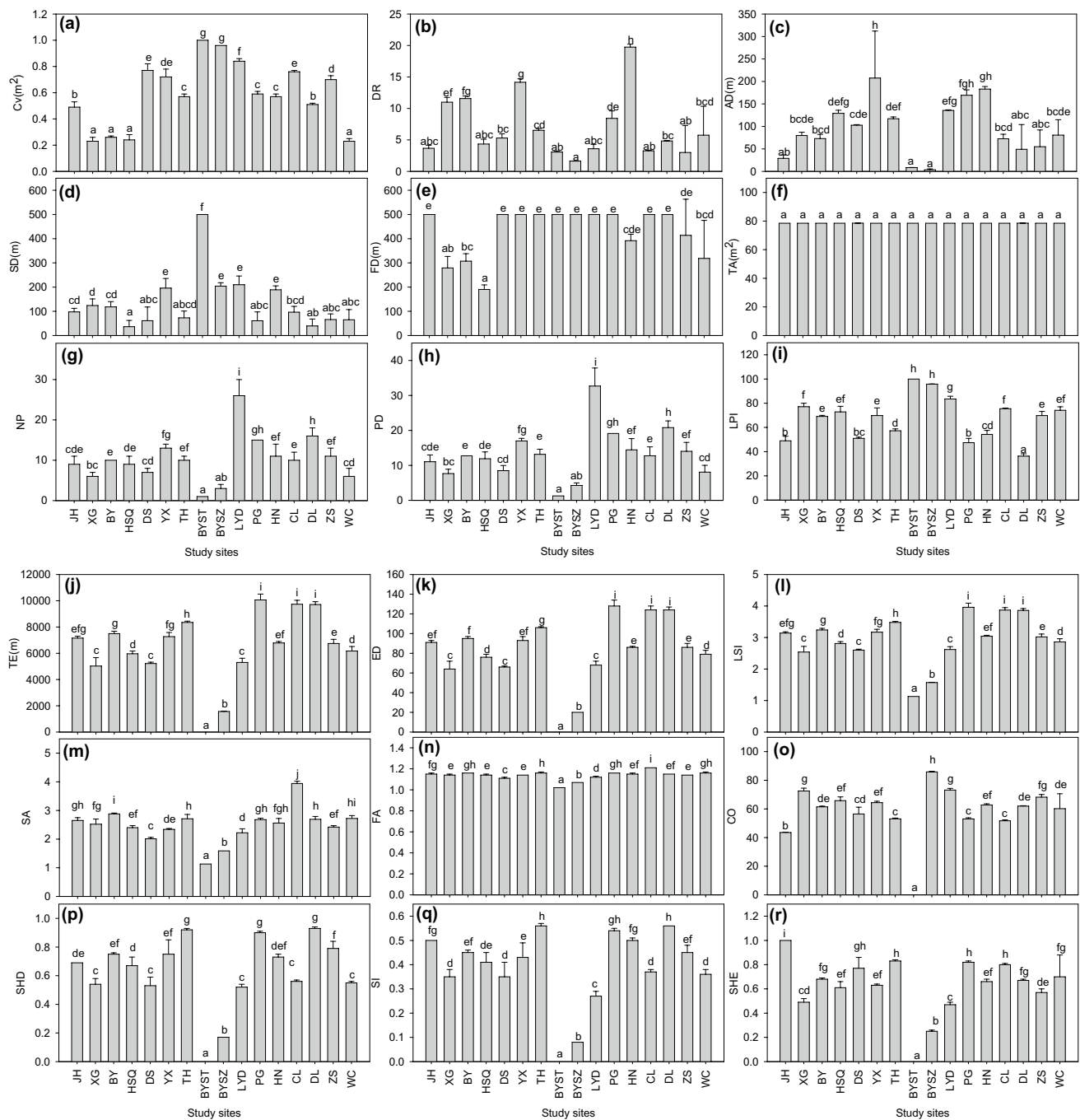
where  $S$  is the number of species in the community, and  $A$  is the unit area.

Based on the land-use map of Guangzhou, 18 landscape indices (Appendix 2) were analyzed by FRAGSTATS 4.0. CANOCO 4.5 was used to analyze the 18 landscape indices and the data set (121 herb-layer species grouped according to 16 sample sites), which in term was used to describe the variances of herb-layer species at different landscape patterns with CCA triplot. One-way ANOVA was used to compare the differences among the 16 study sites for the species diversity indices (H, D, Margalef, Gleason) in herb layers and seed size of *S. superba*. Linear regression models were used to analyze the relationships between landscape indices and species diversity indices (H, D, Margalef, Gleason) in herb layers, as well as the relationships between landscape indices and seed size of *S. superba*. All analyses were conducted using the SPSS (SPSS Software Inc, USA) and statistical significance was determined at  $P < 0.05$ .

## Results

### Landscape pattern indices

Differences in the 18 landscape pattern indices among the 16 sample sites are shown in Fig. 2a–r. Vegetation coverage (CV) is highest in BYST and BYSZ and lowest in XG, WC, HSQ, and BY. Road density (DR) was highest in HN and lowest in BYSZ. The average distance from sample point to road (AD) was highest in YX and lowest in BYSZ and BYST. Shortest distance from sample point to forest edge (SD) was highest in BYST and lowest in HSQ. Farthest distance from sample point to forest edge (FD) was highest in JH, DS, YX, TH, BYST, BYSZ, LYD, PG, CL and DL, and lowest in HSQ. Total landscape area (TA) showed no difference. Number of patches (NP) and Patch density (PD) were highest in LYD and lowest in BYST. Largest patch index (LPI) was highest in BYST and BYSZ and lowest in DL. Total length of patch edges (TE), Edge density (ED) and Landscape shape index (LSI) were highest in PG, CL, and DL and lowest in BYST. Shape Index (SA) and Fractal dimension index (FA) were highest in CL and lowest in BYST. Contagion index (CO) was highest in BYSZ and lowest in BYST. Shannon's diversity index (SHD) was highest in DL, TH, and PG and lowest in BYST. Simpson's diversity

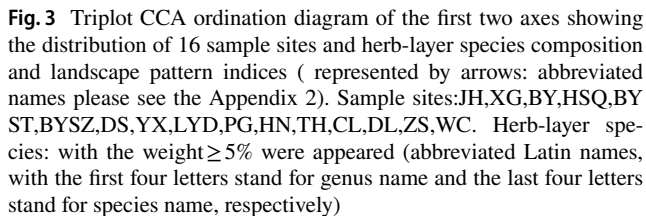


**Fig. 2** The differences of 18 landscape characteristics among 16 sample sites. Error bars indicate one standard deviation. Different letters indicate significant differences at the confidence level of  $P < 0.05$  among the study sites (OneWay ANOVA,  $P < 0.05$ )

index (SI) was highest in TH and DL and lowest in BYST. Shannon's evenness index (SHE) was highest in JH and lowest in BYST.

### Relationships between landscape characteristics and herb-layer plant species composition

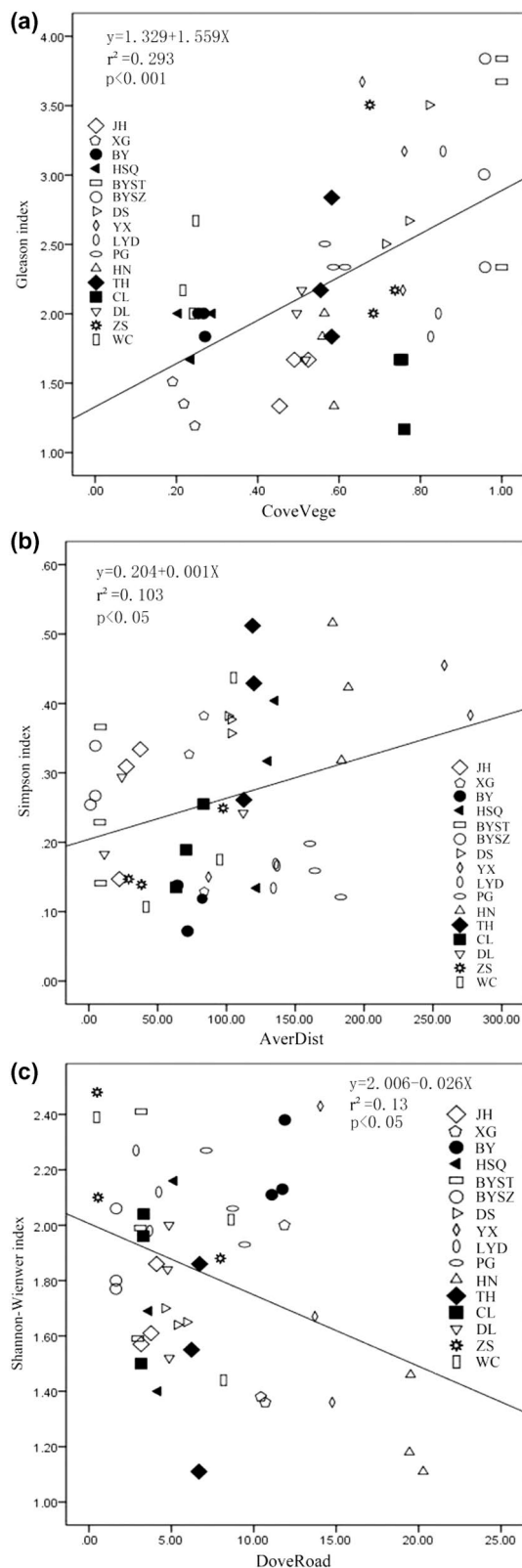
Since the maximum gradient is higher than 4, the plant composition of the plot is sequenced using a single-peak model approach (CCA) for further analysis. Both canonical  $X$  and  $Y$  axes of CCA analysis were significant ( $F = 13.264$ ,  $P = 0.01$ , and  $F = 3.821$ ,  $P = 0.002$ , respectively) (Fig. 3).



From Fig. 3, we found a clear separation of plots between grasslands and other forests associated with different landscape factors. On the one hand, the herb-layer species composition of grasslands (JH, XG, BY, HSQ) was similar, which is located in the upper left corner of Fig. 3. On the other hand, the herb-layer species composition of most plantations and secondary forests (except WC and HN) were similar, which is located in the middle-lower part of Fig. 3. Generally, the herb-layer species in grasslands were different than those in plantations and secondary forests. Herb-layer species with a weight  $\geq 5\%$  are presented in Fig. 3. On one hand, three kinds of dominant herbaceous species are presented in grasslands: (1) invasive species such as *Bidens pilosa*, *Mikania micrantha*, and *Wedelia trilobata*; (2) stress-tolerant species such as *Calystegia hederacea* and *Neyraudia reynaudiana*; (3) weeds *Setaria viridis* and *Celosia argentea*. In general, the common species found in grasslands were pioneer species or perennial herbs. On the other hand, there

In addition, we observed that the density of road, farthest distance from the sample plot center to the edge of stand, and vegetation coverage were the main factors which are showed by the arrows (The longer the arrow, the greater the influence of factors on the distribution of the subjects). Most herb-layer species in plantations and secondary forests were tightly positively related to the farthest distance from sample plot center to edge of stand, vegetation coverage, AD, SD, TA, NP and PD. The herb-layer species in HN were tightly positive related to the density of roads.

The *P* values of regression between LPI, TE, ED, LSI, SHAPE, FRACT, SI, SHE and Margalef indices in herb layers were significant at less than 0.05 ( $R^2=0.085, 0.145, 0.145, 0.145, 0.222, 0.206, 0.124, 0.101$ , respectively) (Fig. 5). We found positive relationships between LPI and Margalef indices in herb layer. However, there were negative relationships between TE, ED, LSI, SHAPE, FRACT, SI, SHE, and Margalef indices in herb layer.



**Fig. 4** Linear regressions between the vegetation coverage and Gleason indices in herb layer, average distance from sample plot center to road and Simpson indices in herb layer, density of road and Shannon–Wiener indices in herb layer

## Relationships between landscape pattern characteristics and seed size of *S. superba*

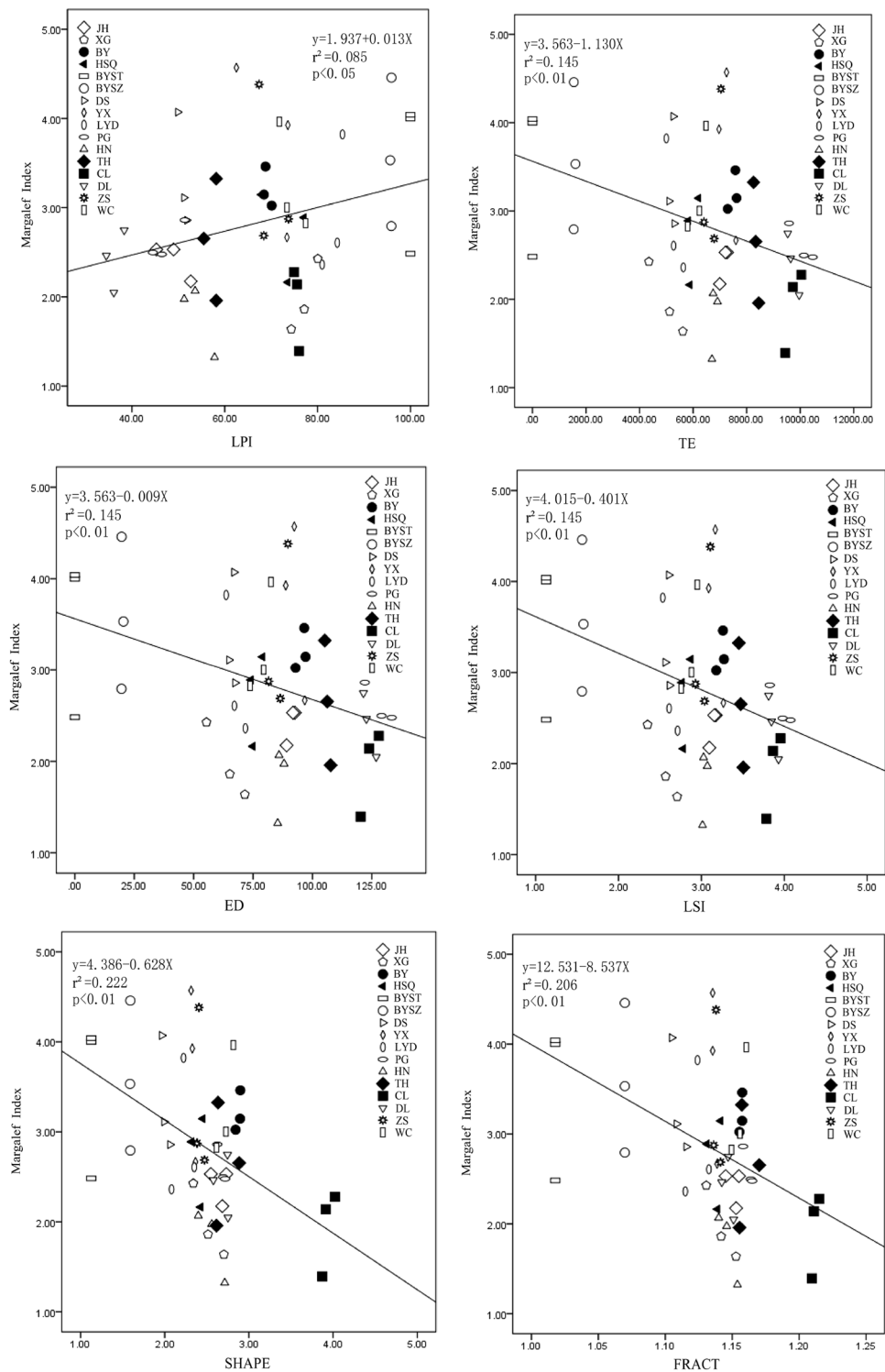
Seed width, thickness, and length of *S. superba* in secondary forests were different among the 9 sample sites (Appendix 4). We found the seed width of *S. superba* were highest in LYD and lowest in HN, BYSZ, and WC. The values for seed length of *S. superba* were highest in PG and lowest in ZS and WC. The values for seed thickness of *S. superba* were highest in BYST and lowest in LYD and PG. In the relationship of landscape pattern characteristics and seed size of *S. superba*. We found negative relationships between the average distance from sample plot center to road and length of seed of *S. superba* (Fig. 6). In contrast, SI and NP were positively correlated with the length and the thickness of the seed of *S. superba*.

## Discussion

### The impact of landscape fragmentation on herb-layer species

Land degradation and excessive disturbance can be assessed by the appearance of dominant plant species in urban environment. The problem of land degradation and ecological restoration can be assessed through the integration of perennial plants into three categories: competitiveness, stress-tolerance, and weed species, which can reveal changes in vegetation in arid regions of Northern Africa (Jauffret and Visser 2003). Our results also found that pioneer plants located in the city center are mostly perennial herbaceous, especially invasive species, stress-tolerant species, and weeds, such as *Bidens pilosa*, *Neyraudia reynaudiana*, and *Setaria viridis*. This is consistent with the results of previous studies carried out in Europe and the United States, which found that the dominant herb-layer species in city centers are mostly weeds (Webb and Fa'Aumu 1999; Fanelli et al. 2006; Knapp et al. 2008). This is probably related to their ability to endure a high degree of interference and population dominance vigorously established in an urban environment. CCA analysis clearly showed that Shannon's evenness index (SHE), Shannon's diversity index (SHD) were positively correlated with the appearance of dominant species in grasslands, the higher the fragmentation index is, the higher frequency of occurrence of the invasive species, stress-tolerant species and weeds would be. This indicated that weeds growing on roadsides and abandoned lands are able to withstand a high degree of human disturbance, such as trampling, which creates open spaces that allow more light to penetrate, prompting early succession, intolerant plants, exotic species, and pioneer species appeared (Heckmann et al. 2008).

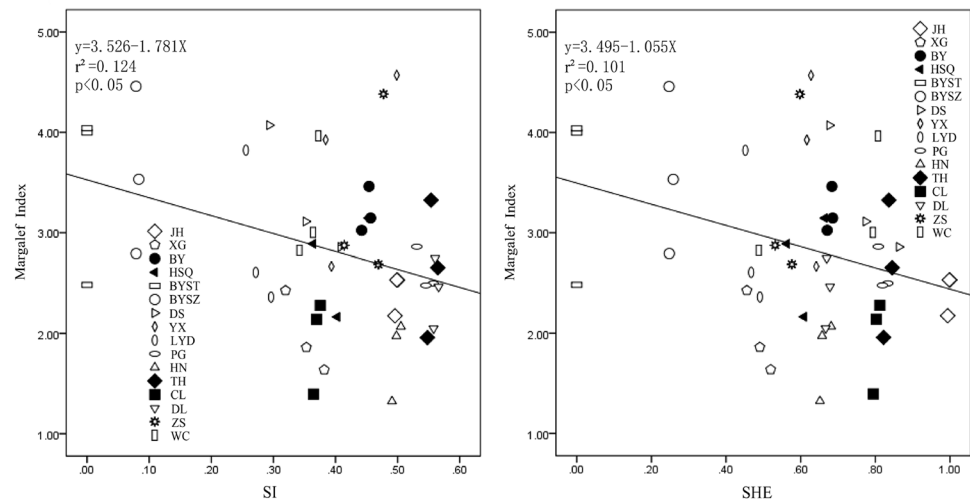
**Fig. 5** Linear regressions between the LPI, TE, ED, LSI, SHAPE, FRACT, SI, SHE and Margalef indices in herb layer



In contrast, the dominant herb-layer species appearing in plantations and secondary forests were native species, especially dominant trees or shrub seedlings, shade or half-shade plants, and ferns, such as *S. superba*, *Dianella ensifolia*, and *Cyclosorus parasiticus*. And we found the dominant herb-layer species in plantations and secondary

forests were positively related with FD, Cv, LPI, and TA. Indicated that landscape patterns have a negative impact on the diversity of herb-layer species. However, the differences in slope, aspect, forest age, or microclimate in plantations and secondary forests can also affect species composition which in turns affect the landscape pattern index. Therefore,

Fig. 5 (continued)



considering all the above: Those native species preferred habitats that contained the following features: (1) farther distance from sample plot center to the edge of stand; (2) higher coverage of vegetation; (3) a larger proportion of the main landscape area. This indicated that large and protected stands are more suitable than grasslands for native species, especially those that prefer environments with shade or half-shade conditions and well-drained soils.

### The impact of laape fragmentation on herb-layer diversity

Fragmentation of landscape patterns caused by urbanization has a negative impact on the diversity of herb-layer plants. On the one hand, compared to shrubs and trees, herb-layer plants are more vulnerable to landscape fragmentation because trees have a strong resistance and lag response (Vellend et al. 2006). Previous studies found that adjoining land-use patterns, distance from forest edge, forest patch size, and the resulting interactions had an impact on plant richness in urban forests. Our results further indicated that the farther the distance the urban vegetation is away from the road, combined with a higher vegetation coverage, the higher the herb-layer diversity is. However, when the density of roads increased, the herb-layer diversity showed a downward trend. Therefore, in the planning of urban green space, it is recommended to increase the buffer zone of urban green space. For the layout of an urban road network, it is suggested to arrange trunk roads between roads and green spaces from urban green spaces as far as possible. This way, can effectively reduce the declining trend of native herbaceous plants in the urban environment, and reduce the frequent occurrence of weeds that occupy the urban vegetation niche.

Furthermore, we found positive relationships between LPI and Margalef indices in the herb layer. Our results showed

that the larger the area of the dominant species (mainly refers to the vegetation landscape), the higher the diversity index is. This is related to the similarity (suitability) of adjacent landscapes, that is, when urban vegetation is close to the surrounding landscapes, the edge effect is occurring between them due to the influence of human activities and landscape patterns, making a number of species gathered among adjacent landscapes, and then the herb-layer diversity is increased.

There was a negative correlation between the edge index (TE and ED), the shape index (LSI, SHAPE, and FRACT), the diversity index (SI and SHE), and the herb-layer Margalef index. The influence of edge index and shape index on the edge effect is very obvious. When the value is large, the shape is complex and the edge effect is stronger, which affects the diversity distribution of the plant. When the diversity index is large, the dominance is generally low, indicating that the landscape is mostly dominated by the dominant patch type. The dominance is low when SHE approaches 1, indicating that there is no obvious dominant patch type or these patches are evenly distributed in the landscape pattern. In summary, higher complexity of the edge shape of urban vegetation patches and higher fragmentation degree of a landscape have brought obvious an edge effect; leading to a decline in herbal diversity index. In studies somewhat similar to ours, Guirado et al. (2007), and Hahs and McDonnell (2006) also indicated that adjacent land-use types, distance from the edge of forest, size of the forest patches, and their resulting interactions have influences on the urban forest plant richness.

Overall, our results indicated that a larger area of dominant type of the landscape (especially the vegetation as the dominant landscape) resulted in a higher herb-layer diversity index. In contrast, a higher fragmentation index resulted in a lower herb-layer diversity index.

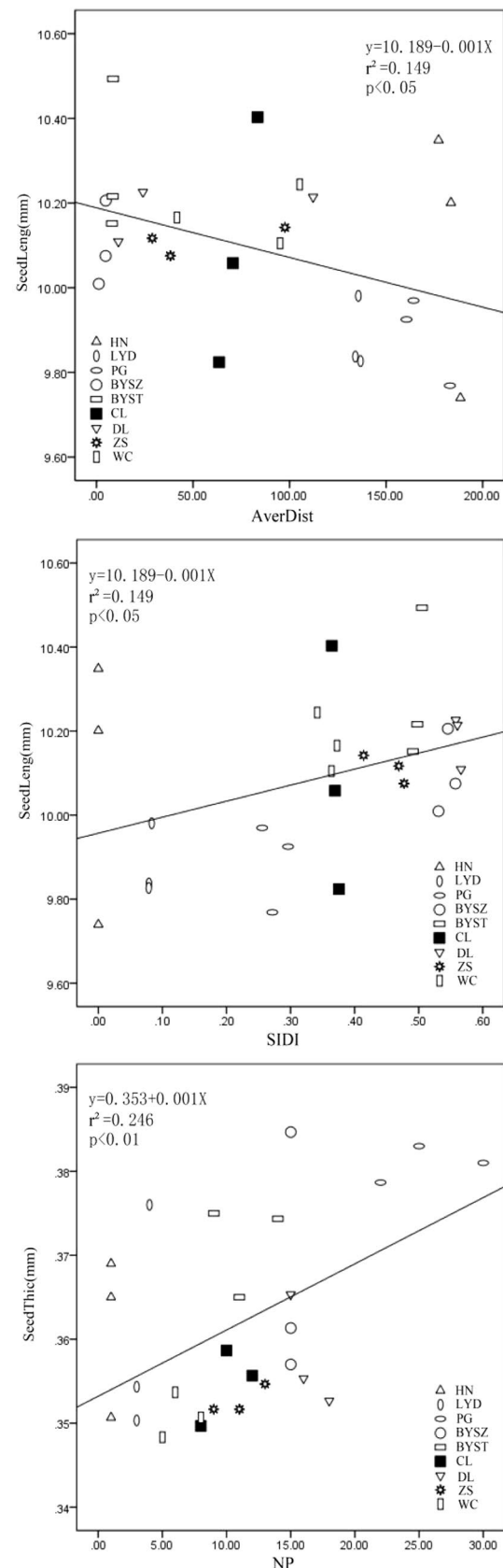
**Fig. 6** Linear regressions between the average distance from sample plot center to road, SI and the length of seed of *S. superba*, NP and the thickness of seed of *S. superba*

### The impact of landscape fragmentation on seed size

Our results showed that a higher landscape diversity (Simpson diversity SI) resulted in a higher fragmentation degree (the number of patches NP), and that a closer disturbance to the road resulted in a larger seed of *S. superba*. These results are consistent with research by Jinwei et al. (2021), who found that the annual plant *Dithyrea californica* in the Solano desert had bigger seed and stronger intraspecific competitive ability than those with smaller ones. It might be explained in three aspects. First, there is a close relationship between seed size and the growth of the plant: (1) Generally species with larger seed has a greater advantage in the seed germination and seedling growth stage; (2) In the case of escaping predation and formation of persistent soil seed banks, the species with smaller seeds have a greater advantage due to the reserve force for regeneration. Furthermore, seed size also affected the mode of seed dispersal. Seeds with vertebrates or ants as vectors are larger than those by wind-borne and adhesive-propagated. Seed size is a key trait that influences plant colonization and reproduction. The species with larger seeds usually have higher seedling viability than those with small ones (Westoby 2002), but the balance between seed size and seed yield should be taken into account (Moles and Westoby 2004). To sum up, in the face of adverse conditions, such as the diversified surrounding landscape type, increased fragmentation, concentrated road network, the dominant species in urban secondary forests had to take the K-breeding strategy, by enhancing the size of the seed to promote the competitiveness of the following aspects: (1) the probability of seed germination; (2) the ability to spread seeds with vectors; and (3) the ability of seedlings viability. Since large seeds are drought-tolerant and competitive, the propagation of urban vegetation increasingly depended on large seeds (Westoby 2002).

### Conclusion

Fragmentation of landscape patterns caused by urbanization has a negative impact on the diversity of herb-layer plants. The bigger the area of the dominant type of landscape (especially the vegetation as the dominant landscape) is, the higher the herb-layer diversity index is. In contrast, the higher the fragmentation index is, the lower the herb-layer diversity index is. In addition, the frequency of invasive species, stress-tolerant species, and weeds would increase when the fragmentation degree rises. Therefore, large and



protected stands are more suitable than grasslands for native species, especially those that prefer environments with shade or half-shade conditions and well-drained soil, such as dominant trees or shrubs seedlings, shade or half-shade plants, and ferns.

To sum up, there are two ecological strategies adopted by plant communities adapting to urbanization disturbance: (1) weeds dominating in grasslands, with high reproductive and dispersal ability that adopted r-selection strategy; (2) dominant species in forests, with higher survival rate, larger individuals and longer life-spans adopted K-selection strategy, in order to resist disturbance from diverse landscape types, high fragmentation degree, and road, combined with that increased seed size to increase their viability and settlement ability. The above findings have important implications for the management of remnant forests in an urban area. Landscape-based regional policy is needed to protect native herbaceous plants, and avoid the frequent occurrences of weeds. When planning urban green spaces, it is recommended to increase the buffer zone of urban green spaces; when designing the layout of an urban road network, it is suggested to arrange the trunk roads with a high degree of interference as far as possible from the urban green spaces.

**Supplementary Information** The online version contains supplementary material available at <https://doi.org/10.1007/s42965-022-00255-9>.

**Acknowledgements** We thank the Feng rongguang for his assistance. We also thank Liu hongxiao for their useful suggestions. Thanks also to Prof. Bruce Jaffee for improving the quality of English writing of this paper, and critical comments from reviewers. This study was funded by the National Natural Science Foundation of China (32071578); Fujian Provincial Natural Science Foundation of China (2021J01133) and Subject Cross-Integration Project (YSYL-xkj-8).

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